THE METEOROLOGICAL MAGAZINE

M.O. 441

AIR MINISTRY : METEOROLOGICAL OFFICE

Vol. 74 DECEMBER, 1939 No. 887

THE LUNAR TIDE IN THE ATMOSPHERE

BY PROFESSOR S. CHAPMAN, F.R.S.

From the writer's Presidential Address to the Association for Meteorology, at the Washington Assembly (September, 1939) of the International Union for Geodesy and Geophysics.

Laplace, in 1825, seems to have been the first to try to determine, from barometric observations, whether the moon produces a tide in the air as it does in the sea. He used Paris data (8 years), as did Bouvard (11 years) in 1828, and Eisenlohr (22 years) in 1843, but all without success. Lefroy in 1842, from 17 months' bi-hourly observations at St. Helena, first determined this air-tide; in 1852 Elliot determined it at Singapore from 5 years' data. From 1871 onwards the air-tide has been determined regularly at Batavia, by Bergsma and succeeding directors, and its value there is now known with considerable accuracy. St Helena, Singapore and Batavia are of course all in the tropics, where the barometric changes are usually much smaller and more regular than in higher latitudes: in the tropics also the air-tide, according to theory, should be larger than elsewhere; these combined reasons explain why the tropical air-tide was readily determined, whereas until 1918 all efforts to find it in non-tropical records were unsuccessful—e.g., by Neumayer for Melbourne, Börnstein for Keitum, Morano for Rome, and Airy for Greenwich (20 years' data).

In 1918 I determined the Greenwich air-tide from 64 years' hourly data, by rejecting the data (about two-thirds of the whole) for all days on which the barometric range exceeded 0·1 inch: the result is shown in Fig. 1.

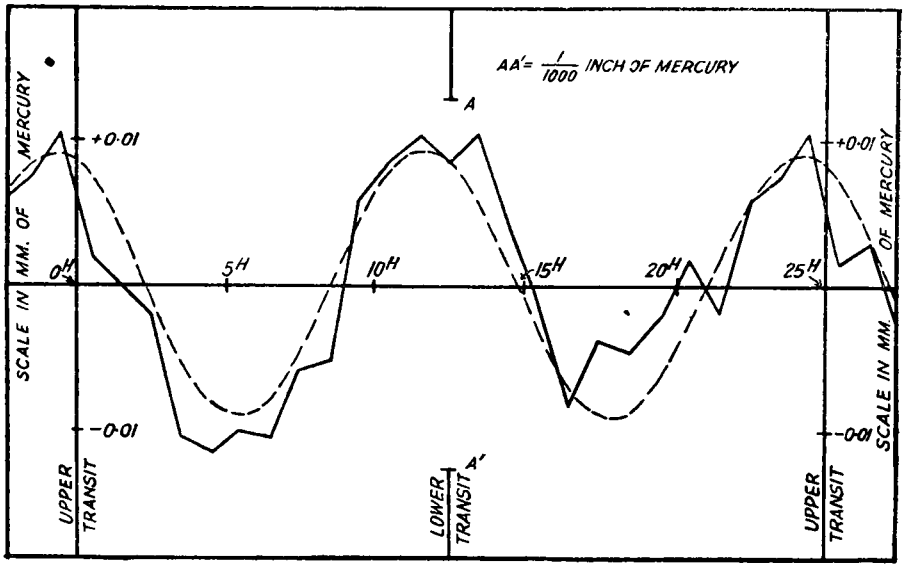

Fig. 1.—The lunar semi-diurnal tide in the atmosphere at Greenwich as determined from the Greenwich records of barometric pressure, 1854–1917.

The broken line indicates the lunar semi-diurnal component and the difference between this and the computed variation (the full line) may be attributed to accidental causes.

High tide occurs there twice daily, just before the moon's upper and lower transits: the tidal range is less than 0·001 inch of mercury: that such a small regular variation can be disentangled from the irregular variations, of range more than 3,000 times as great, is a striking illustration of the law of errors. The rejection of the days of range exceeding 0·1 inch was not due to any expectation that the tide was not present on such days, but simply because it was not possible to reduce the average of the irregular variations on such days, with the amount of material available, to the very small value needed to disclose the minute lunar tide.

In 1918 the air-tide was thus known at three tropical stations and one non-tropical: its value has since been determined at 50 more stations: these results are due as follows: to Bartels, three stations, Hamburg and Potsdam (non-tropical) and Dar-es-Salaam (Bartels has also introduced important improvements in the calculations, and in the estimation of the probable errors): to Pramanik and his colleagues, Bombay, and a pair of adjacent Indian stations at very different heights, Kodaikanal and Periyakulam: to Robb and Tannahill, Glasgow: the remainder are due to the writer and his colleagues and assistants: the rate at which we have been able to make the calculations has increased about

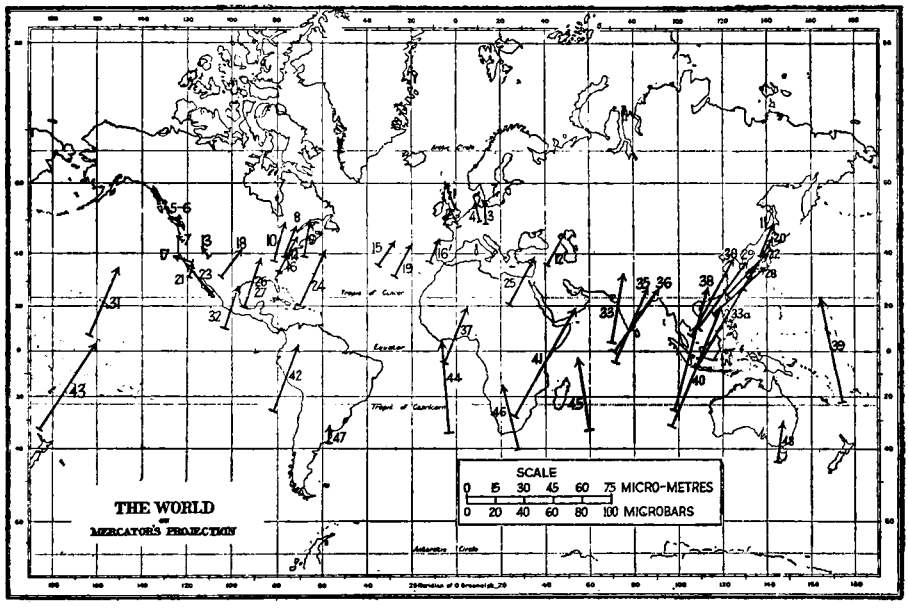

Fig. 2.—Geographical distribution of amplitude and phase of annual lunar atmospheric tide.
(Vector-arrows *centered* at stations.)

three-fold since, in 1930, a set of Hollerith punching, sorting and tabulating machines was made available for this work, by the courtesy of the British Tabulating Machine Co., Ltd.; since then no less than 28 new determinations have been made by this means, of which 17 are not yet published.

The main results are illustrated in Fig. 2, which shows the geographical distribution of the air-tide. The map shows a number of arrows, each of which refers to the air-tide at the point on the map at the centre of the arrow shaft. The length of the arrow indicates the semi-range of the tide, in mm. of mercury or in microbars, according to the scales shown: and the direction of the arrow indicates the times of high tide (twice daily) as shown by the arrow regarded as the hour-hand of a clock keeping lunar time, so that 12 o'clock corresponds to the upper or lower transit of the *moon* instead of the sun.

All the arrows point *upwards,* and the majority point towards the right, indicating high tide somewhat after lunar transit, though at some stations it occurs in advance of the moon's meridian passage.

On the whole the arrows are longest in the tropics, and shortest in the highest latitudes: this is what tidal theory would suggest. But there are notable departures from this rule (and these are in the main real, and not due merely to accidental errors, though the results are certainly affected to some extent by such errors): for example, the air-tide at Melbourne (48) is notably greater than at Buenos Ayres (47), in almost the same latitude; the numbers in brackets are those assigned to the corresponding arrow on the map. At the equator the pressure range due to the lunar air-tide is about 0·12 mm. of mercury, corresponding to the weight of about 4 feet of air of normal density.

Some specially striking irregularities in the geographical distribution of the tide are found in North America. Along the eastern part, and indeed southwards from Montreal (8) and St. John (9) as far as Mexico City (32) and Lima (42), and eastwards to Bermuda (24), the air-tide has a normal and regular distribution, with nearly the same phase at all the stations. At Dodge City (18), in the middle of the land mass, the phase is fairly regular, but the amplitude is somewhat smaller than at the more easterly stations in the same latitude. Further to the west the tide becomes

increasingly abnormal, either in the smallness of its amplitude, or in its unusual phase, or in both these respects. This result was first indicated by the determinations for five Canadian stations: the amplitudes found for Victoria (6) and Vancouver (5), in the far west, were abnormally small. This is now confirmed by the determination for Portland (Oregon) (7) not far to the south. At all three stations the amplitudes are so small that the phases there (or the times of high tide) are uncertain.

The tide at Salt Lake City (13) is notable not only for its small amplitude, but also for its early maximum; also at San Francisco (17) and San Diego (23), on the western coast, the phase is unusually early—two hours before the moon transits. At the neighbouring high-level stations of Mount Wilson Observatory (21) and Mount Hamilton (Lick) the tide is similar in size (rather small for the latitude) but the phase is roughly normal, with high tide after the moon's transit. These remarkable results well repay the labour of determining the tide at these various points in the United States, and render it desirable to pursue the study further, both in North and South America. It seems scarcely open to doubt that these anomalies in the distribution of the tide are due to the great mountain-chain along the west of the continent.

In this respect the lunar pressure variation contrasts strongly with the solar 12-hourly pressure wave, whose distribution over North America shows a notable uniformity of phase, with maximum at about 10 o'clock. The distribution of the amplitudes is also regular: it depends on the latitude, but only to a slight extent on the longitude, and there is no notable reduction of amplitude on the western coast.

The great mountain chain in North and South America makes this region one of particular interest for the study of the air-tide. Determinations for the two available pairs of adjacent stations at considerably different levels show interesting differences, already

referred to. Examination of the probable errors of the results shows that these differences are real, and that at Mount Wilson (height 1,783 metres) high tide in the air pressure occurs over an hour later than at San Diego (26 metres), and similarly for Mount Hamilton (1,284 metres) and San Francisco (47 metres): these differences much exceed those between the times of maximum pressure in the solar twelve-hourly wave at the same two pairs of stations. In India, on the other hand, Pramanik found no appreciable difference between the air-tides at Kodaikanal (314 metres) and Periyakulam (2,563 metres), despite the greater height-difference of these adjacent stations.

So far the annual mean value of the air-tide has been considered: but it is found that the amplitude and time of high tide are not constant throughout the year. The change in the tide from month to month or season to season has been determined at many stations. Its most notable feature at almost all stations is that in December or January high tide occurs decidedly later (by over an hour) than in April or May: this is the case both north and south of the equator, though on the western coast of North America some stations are anomalous in this as in other respects. This change of phase (that is, of the time of high tide), as well as the associated but minor changes in the amplitude, is not a seasonal change in the usual sense of this term: the seasons depend on the sun's declination, and when it is summer in one hemisphere it is winter in the other: when the sun crosses the equator, the seasons are reversed, and the hemispheres undergo opposite seasonal changes. As regards the air-tide, its phase varies similarly in both hemispheres at once, hence the change is properly called an annual one.

The well-known solar twelve-hourly variation of the barometer also undergoes an annual variation, but of smaller magnitude and different type: in this variation high pressure occurs *earliest* in December (not latest, as for the lunar air-tide) and latest in July.

The intensity of the moon's tidal force upon the earth varies by ±20 per cent. with the moon's changing distance. The lunar air-tide would be expected to show a corresponding variation of amplitude, and this has been looked for in the determinations for many stations. A change of the right sign and of about the right magnitude is found at some stations, but at others the results have agreed less well with the theory. This is perhaps because of statistical difficulties in the computations, not yet properly understood. It is hoped that these will ere long be overcome, and that the influence of lunar distance upon the air-tide will be definitely determined.

The pressure variations in terms of which we have thus far discussed the lunar air-tide are of very low frequency: their period of half a lunar day corresponds to a frequency of 705 oscillations per year. It might well be thought that such low-frequency pressure-variations would be isothermal, and Laplace in his theory of atmospheric tides assumed this. But here he fell into the same error which he himself corrected with reference to Newton's theory of the velocity of sound. The rapid oscillations in sound waves, with a frequency of some hundreds per second, occur adiabatically, and by allowing for this Laplace was able to revise Newton's faulty value of the velocity of sound and obtain the observed value. The slow tidal pressure variations also occur adiabatically. This is because of the great length of the lunar tidal wave which moves round the earth, following the moon; the heat generated by the tidal compression cannot traverse this great distance in the time available, nor can it escape upwards or downwards at a sufficient rate. These conclusions, indicated by theoretical examination, have been confirmed from actual observation by my determination of the lunar semi-diurnal variation of air-temperature at Batavia (40), having an amplitude of 0·009° C., with maximum temperature occurring at the same time as high (air-) tide there.

Horizontal air-currents with a period of half a lunar day must be associated with the air-tide. Their expected velocity is about 2 cm/sec. or about 70 metres per hour. This is very small compared with the normal wind-velocities, but I think there is a possibility of determining a lunar semi-diurnal variation of the wind from the long series of records at Batavia, and work on this problem has already been begun. Such work would be facilitated if some observatory, especially in the tropics, would measure or tabulate the wind *components*, converting the records of velocity and direction into those of east-west and north-south velocities, preferably tabulating them with the addition of a constant which would make all the hourly values positive.

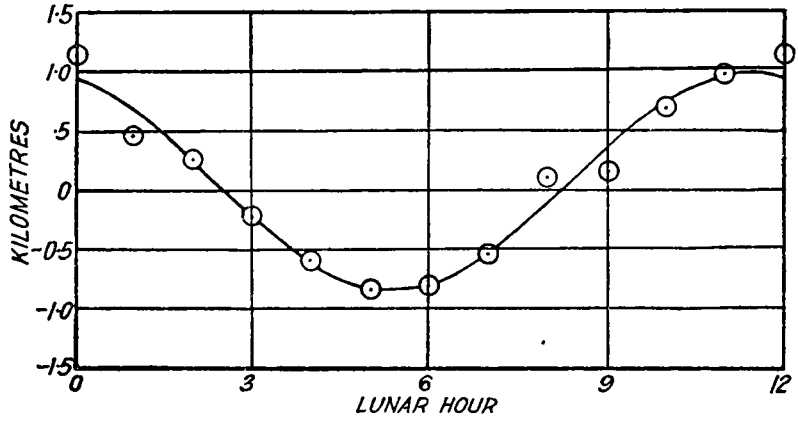

Fig. 3.—Lunar semi-diurnal oscillation of E-region of the ionosphere for the period, August 3rd, 1937 to July 11th, 1938, at Cambridge.

The preceding account of the lunar air-tide is based on the evidence for the tide to be found (like the proverbial needle) in the great haystack of old meteorological records. But the tide is also known by its effects in two other distinct ways. The lunar tidal motion of the air at high levels, where the air is ionized and therefore electrically conducting, acts like the motion of the armature in the magnetic field of a dynamo; electric currents are generated, because the air is moving in the

field of the great magnet, the earth itself. These electric currents, which amount in the aggregate to 20 or 30 thousand amperes, themselves exert a minute magnetic field, which produces a lunar daily magnetic variation at the earth's surface. This can be disentangled from long series of magnetic records (or short series in low latitudes) just like the lunar tidal barometric variation. This gives us interesting information (not yet fully interpreted) about the lunar tidal air-currents at high levels in the atmosphere.

The second and most recently discovered non-meteorological indication of the lunar air-tide is a variation of level of the E-layer in the ionosphere, as found by radio determinations of the height of this layer. Figure 3 illustrates this variation, which was detected by Appleton and Weekes from radio measurements at Cambridge, England: the phase is in good accordance with the phase of the lunar pressure variation at Greenwich (Fig. 1) but the amplitude is some thousands of times larger than could have been expected until recently.

These facts about the lunar atmospheric tide, as determined from various kinds of observation, are more complex and more puzzling than would seem likely *a priori,* in view of the simplicity of the lunar tidal field of force. The complications in the tide are partly due to the irregular surface on which the atmosphere rests, and to the changes of level of this surface, due to the sea-tides and the earth-tides. But one main cause is the complex structure of the atmosphere itself, which is the dynamical system on which the moon acts. I believe that the lunar atmospheric tide has a valuable contribution to make to our knowledge of this structure, but the story of the theoretical questions connected with the tide is too long to be entered upon here.

LETTERS TO THE EDITOR

Altocumulus-castellatus Cloud observed in a Polar Current

On Sunday morning, October 22nd, 1939, at about 10h. 30m. G.M.T. I observed a fine altocumulus-castellatus cloud at Eastbourne. It was seen out at sea looking towards Beachy Head and lasted for about half an hour. The day was cold and bright with a moderate NNE wind. It seems curious that one should see this cloud in a polar current. I wonder whether the action of the warmer sea accounted for the formation of the cloud and whether other readers of *The Meteorological Magazine* have observed clouds of this kind in polar air.

J. MONGER.

46, Great Bushey Drive,
Totteridge, N.20.
October 27th, 1939.

Mr. C. K. M. Douglas remarks " Probably the clouds were at no great height. I have seen clouds quite low over the sea with a structure resembling altocumulus-castellatus."

NOTES AND NEWS

The Weather Cock.

Many people, both meteorologists and others, must have asked themselves from time to time what a cock had to do with meteorology. Sir Napier Shaw recently drew my attention to a note by Gwyneth Pennethorne in a local Magazine which may explain the origin of the connexion.

The note was to the effect that in the 9th Century the reigning Pope Nicholas I, much concerned at the prevalence of lying and prevarication, directed that cocks

should be placed at the tops of spires and towers of churches so that the people might have continually before them a reminder of the denial of Peter and the lesson which it taught, and might thereby become more truthful. The Pope was in fact a propagandist and the cocks propaganda of the higher type.

It seems likely that when the cocks were first placed on churches in obedience to this wise order they were fixed cocks, and when strong winds arose they were blown down. The obvious remedy was adopted, namely, to make the cocks rotate with the wind and so present a smaller surface to its force. In this way they not only maintained their lofty situation when the storms arose and beat upon them, but they also became indicators of the direction of the wind and thereby qualified as meteorological instruments: not only warners against lying, but purveyors of truth. Indeed their original deterrent negative purpose has been forgotten, and their secondary instructive positive purpose now alone remains: but even that was perverted by the ignorance of man who called them weather-cocks, not wind-cocks as they should have been called when they lost their significance as " Peter-cocks ". Perhaps it is time they regained it.

E. GOLD.

December Frosts in Early Days (1141, 1241 and 1269)

Many references can be found in the Annals to severe frosts in this month. A picturesque incident in connection with such a frost is found in 1141 when Stephen was besieging Oxford. Henry of Huntingdon states " The same year the King besieged the Empress at Oxford from after Michaelmas to Advent. At the end of which, not long before Christmas, the Empress escaped across the Thames, which was then frozen over, and, wrapped in a white cloak, deceived the eyes of the besiegers, dazzled by the reflection of the snow."

A century later, in 1241, Matthew Paris thus describes December of that year "In the time of winter also, namely, in the advent of the Lord, frost and snow and intolerably bitter cold covered the earth and so hardened it, binding rivers, that numbers of birds gathered together and perished miserably, the like of which no one remembered having seen before."

The Annals of Oseney Abbey refer to a glazed frost during the severe wintry weather of December, 1269, ". . . . and it happened in this frost of wonderful duration that, as soon as rain fell from the sky, so it froze, so that, by reason of the slipperiness of this frost no one could ride on the same, nor turn in any direction without great peril of his life or limbs, or damage to his head."

C. E. BRITTON.

Sunshine, November, 1939

The distribution of bright sunshine for the months was as follows:—

	Total hrs.	Diff. from average hrs.		Total hrs.	Diff. from average hrs.
Stornoway	38	− 8	Chester	45	− 8
Aberdeen	56	− 3	Ross-on Wye	44	−19
Dublin	42	−29	Falmouth	47	−29
Birr Castle	39	−22	Gorleston	..	..
Valentia	36	−27	Kew	36	−17

Kew temp., mean, 49·1° F. diff. from average +4·8° F

General Rainfall, November, 1939

	Per cent.
England and Wales	178
Scotland	142
Ireland	197
British Isles	171

OBITUARY

DR. R. A. SAMPSON, F.R.S., Astronomer Royal for Scotland and Professor of Astronomy in the University of Edinburgh from 1910 to 1937, died suddenly at Bath on November 7th.

Professor Sampson was born in County Cork in 1866. He was educated at Liverpool Institute and at St. John's

College, Cambridge, graduating as third Wrangler in 1888. In 1890 he gained the first Smith's Prize and became a Fellow of his College and in 1891 became the first Isaac Newton Student. For two years he was a lecturer in King's College, London, for a further two years Professor of Mathematics at the Durham College of Science, Newcastle-on-Tyne, and then, until 1910, Professor in the University of Durham.

Amongst his scientific work his most important researches were in connexion with the satellites of Jupiter, for which, in 1928, the Royal Astronomical Society awarded him its Gold Medal. At the Royal Observatory, Edinburgh, he conducted successfully the measurement of 64 of the brighter stars and did important work on the determination and recording of time.

Professor Sampson was an Hon. D.Sc. of Durham and L.L.D. of Glasgow and for a number of years was General Secretary of the Royal Society of Edinburgh. He represented the Royal Society of Edinburgh on the Meteorological Committee, London, and on the National Committee for Geodesy and Geophysics and represented the Royal Society of London on the Advisory Committee for the Meteorological Office, Edinburgh, of which also for a number of years he was Vice-Chairman.

In scientific work he was a pioneer and showed great foresight, as well as patience and determination and "beneath a superficial appearance of austerity he managed to conceal a capacity for enjoying life and assisting others to do likewise." The writer will always remember an expedition made in 1931 in his company to the top of Ben Nevis, the admiration he expressed for the pioneers who had planned and built the road and the Observatory, the masons whose stonework was "untouched by time and might last as long as the mountain" and the observers who maintained hourly observations for 21 years.

Professor Sampson is survived by his wife and four sons and daughters.

A. H. R. G.

Rainfall: November, 1939: England and Wales

Co.	Station.	In.	Per cent of Av.	Co.	Station.	In.	Per cent of Av.
Lond'n	Camden Square.....	4·98	211	*Warw*	Alcester, Ragley Hall.	..	..
Surrey	Reigate, Wray Pk. Rd.	5·58	179	,,	Birminghm, Edgbaston	4·57	192
Kent .	Tenterden, Ashenden.	5·44	180	*Leics* .	Thornton Reservoir...	4·17	185
,, .	Folkestone, I. Hospital	5·91	..	,, .	Belvoir Castle.....	3·28	147
,, .	Margate, Cliftonville..	3·83	159	*Rutl'd*	Ridlington	3·47	151
,, .	Edenb'dg..Falconhurst	6·15	17.	*Lincs*.	Boston, Skirbeck.....	3·90	195
Sussex	Compton, Compton Ho	7·97	209	,, .	Cranwell Aerodrome..	3·51	188
,, .	Patching Farm.....	7·62	214	,, .	Skegness, Marine Gdns	3·78	175
,, .	Eastbourne, Wil. Sq..	7·0	201	,, .	Louth, Westgate.....	4·45	172
Hants .	Ventnor, Roy.Nat.Hos.	7·98	249	,, .	Brigg, Wrawby St....	4·14	..
,, .	Southampton, East Pk	6·35	202	*Notts* .	Mansfield, Carr Bank..	3·77	155
,, .	Ovington Rectory....	7·07	213	*Derby*.	Derby, The Arboretum	..	..
,, .	Sherborne St. John...	6·41	225	,, .	Buxton, Terrace Slopes	8·51	182
Herts .	Royston, Therfield Rec	3·52	151	*Ches* .	Bidston Obsy.....	4·41	176
Bucks.	Slough, Upton.....	4·71	212	*Lancs*.	Manchester, Whit. Pk.	5·35	202
Oxford	Oxford, Radcliffe.....	4·11	179	,, .	Stonyhurst College...	7·93	176
N'hant	Wellingboro,Swanspool	3·30	153	,, .	Southport, Bedford Pk	4·74	151
,, .	Oundle	3·15	..	,, .	Ulverston, Poaka Beck	..	..
Beds .	Woburn, Exptl. Farm.	3·59	160	,, .	Morecambe.....	4·84	128
Cambs	Cambridge, Bot. Gdns.	2·87	149	,, .	Blackpool.....	4·36	126
,, .	March	..	..	*Yorks*.	Wath-upon-Dearne...	3·40	167
Essex.	Chelmsford,CountyGns	4·01	178	,, .	Wakefield,Clarence Pk.	3·56	168
,, .	Lexden Hill House....	4·19	..	,, .	Oughtershaw Hall....	11·16	..
Suff .	Haughley House.....	3·54	..	,, .	Harrog'te,HarlowMoor	4·11	149
,, .	Campsea Ashe, High Ho	4·63	209	,, .	Hull, Pearson Park...	3·55	162
,, .	Lowestoft Sec. School.	..	..	,, .	Holme-on-Spalding...	4·01	184
,, .	Bury St. Ed.,WestleyH	4·06	177	,, .	Felixkirk, Mt. St. John	2·34	94
Norf..	Wells, Holkham Hall.	3·69	172	,, .	York, Museum.....	2·80	134
Wilts .	Porton, W.D. Exp'lStn	5·37	205	,, .	Scarborough.....	2·80	113
,, .	Bishops Cannings	5·76	201	,, .	Middlesbrough.....	1·64	77
Dorset	Weymouth, Westham.	6·07	196	,, .	Baldersdale, Hury Res.	5·93	160
,, .	Beaminster, East St ..	8·80	222	*Durhm*	Ushaw College.....	2·46	97
,, .	Shaftesbury	7·46	..	*Norl'd*	Newcastle, Leazes Pk.	2·37	101
Devon.	Plymouth, The Hoe...	7·11	195	,, .	Bellingham, Highgreen	4·37	127
,, .	Holne, Church Pk.Cott	15·06	234	,, .	Lilburn Tower Gdns..	2·89	86
,, .	Teignmouth, Den Gdns	5·85	183	*Cumb*.	Carlisle, Scaleby Hall.	4·32	144
,, .	Cullompton	8·09	235	,, .	Borrowdale,Seathwaite	25·00	195
,, .	Sidmouth, U.D.C.....	4·73	..	,, .	Thirlmere,DaleHeadH.	14·82	153
,, .	Barnstaple,N. Dev.Ath	7·57	193	,, .	Keswick, High Hill...	9·46	167
,, .	Dartm'r,Cranmere P'l	..	..	,, .	Ravenglass, The Grove	4·65	104
,, .	Okehampton, Uplands.	14·27	268	*West* .	Appleby, Castle Bank.	4·80	145
Cornw	Redruth, Trewirgie...	..	..	*Mon* .	Abergavenny, Larchf'd	7·22	189
,, .	Bude, School House ..	..	..	*Glam* .	Ystalyfera, Wern Ho..	16·07	245
,, .	Penzance, MorrabGdns	7·36	152	,, .	Treherbert, Tynywaun	20·44	..
,, .	St. Austell, Trevarna..	8·44	172	,, .	Cardiff, Penylan.....	8·71	215
Soms .	Chewton Mendip.....	11·60	271	*Carm* .	Carmarthen,M.&P.Sc.	12·24	238
,, .	Long Ashton	7·06	223	*Card* .	Aberystwyth	8·87	..
,, .	Street, Millfield	5·70	210	*Radn'r*	Bir. W. W. Tyrmynydd	14·31	215
Glostr.	Blockley	4·22	..	*Mont* .	Lake Vyrnwy.....	13·15	237
,, .	Cirencester, Gwynfa ..	5·98	201	*Flint* .	Sealand Aerodrome...	4·04	173
Here .	Ross-on-Wye	4·22	167	*Mer* .	Blaenau Festiniog....	18·98	196
,, .	Kington, Lynhales....	6·23	193	,, .	Dolgelley, Bontddu...	11·17	180
Salop.	Church Stretton.....	5·66	..	*Carn* .	Llandudno	3·87	134
,, .	Shifnal, Hatton Grange	3·94	165	,, .	Snowdon, L. Llydaw 9	23·85	..
,, .	Cheswardine Hall	4·88	188	*Angl* .	Holyhead, Salt Island.	3·90	94
Worc .	Malvern, Free Library.	4·20	167	,, .	Lligwy.....	..	..
,, .	Ombersley, Holt Lock.	3·70	162	*I.Man*	Douglas, Boro' Cem...	5·39	114

Rainfall: November 1939: Scotland and Ireland

Co.	Station.	In.	Per cent of Av.	Co.	Station.	In.	Per cent of Av.
Guern.	St.PeterP't.GrangeRd.	5·06	120	*R&C.*	Stornoway, C.G.Stn...	6·36	115
Wig .	Pt. William, Monreith.	4·77	111	*Suth .*	Lairg	4·85	122
,, .	New Luce School.....	7·73	151	,, .	Skerray Borgie.....	5·55	..
Kirk .	Dalry, Glendarroch...	9·11	152	,, .	Melvich	6·71	168
Dumf.	Eskdalemuir Obs.....	9·28	160	,, .	Loch More, Achfary..	9·65	113
Roxb .	Hawick, Wolfelee	4·74	122	*Caith .*	Wick	4·11	131
,, .	Kelso, Broomlands....	2·61	113	*Orkney*	Deerness	..	..
Peebs .	Stobo Castle.....	6·84	207	*Shet .*	Lerwick Observatory.	5·04	118
Berw .	Marchmont House....	3·16	105	*Cork .*	Cork, University Coll.	9·00	224
E.Lot.	North Berwick Res...	..	..	,, .	Roches Point, C.G.Stn.	7·32	174
Midl .	Edinburgh, Blackfd. H	3·51	157	,, .	Mallow, Hazlewood ..	9·61	..
Lanark	Auchtyfardle	8·42	..	*Kerry.*	Valentia Observatory.	10·08	184
Ayr .	Kilmarnock, Kay Park	8·14	..	,, .	Gearhameen	22·2	229
,, .	Girvan, Pinmore	8·04	151	,, .	Bally McElligott Rec.	9·56	..
,, .	Glen Afton, Ayr San..	12·10	220	,, .	Darrynane Abbey....	9·26	182
Renf .	Glasgow, Queen's Park	8·23	221	*Wat .*	Waterford, Gortmore.	6·25	169
,, .	Greenock, Prospect H.	11·24	185	*Tip .*	Nenagh, Castle Lough.	10.45	260
Bute .	Rothesay, Ardencraig.	9·37	185	,, .	Cashel, Ballinamona..	9·05	262
,,	Dougarie Lodge.....	7·62	145	*Lim .*	Foynes, Coolnanes....	9·00	221
Argyll	Loch Sunart, G'dale..	10·33	138	,, .	Limerick, Mulgrave St.	..	..
,,	Ardgour House	14·56	..	*Clare .*	Inagh, Mount Callan..	15·69	..
,,	Glen Etive	15·50	150	*Wexf .*	Gorey, Courtown Ho..	5·96	171
,,	Oban	..	..	*Wick .*	Rathnew, Clonmannon	5·18	..
,,	Poltalloch.....	10·22	182	,, .	Blessington Rectory..	..	..
,,	Inveraray Castle	15·09	179	*Carlow*	Bagnalstown FenaghH	7·22	216
,,	Islay, Eallabus	..	..	,, .	Hacketstown Rectory.	7·94	204
,, .	Mull, Benmore.....	14·90	103	*Leix .*	Blandsfort House	7·82	234
,,	Tiree	7·04	146	*Offaly.*	Birr Castle	7·39	238
Kinr .	Loch Leven Sluice....	6·04	168	*Dublin*	Dublin, Phoenix Park.	4·26	151
Fife .	Leuchars Aerodrome..	4·24	185	*Meath.*	Kells, Headfort.....	6·99	206
Perth .	Loch Dhu	13·80	159	*W.M .*	Moate, Coolatore.....	6·66	..
,, .	Crieff, Strathearn Hyd.	6·44	148	,, .	Mullingar, Belvedere..	7·67	225
,, .	Blair Castle Gardens..	5·42	154	*Long .*	Castle Forbes Gdns ..	8·40	233
Angus.	Kettins School.....	5·93	191	*Galway*	Galway, Grammar Sch.	9·12	224
,, .	Pearsie House	6·32	..	,, .	Ballynahinch Castle ..	9·89	165
,, .	Montrose, Sunnyside..	3·80	143	,, .	Ahascragh, Clonbrock.	9·62	239
Aberd.	Balmoral Castle Gdns.	3·60	98	*Rosc .*	Strokestown, C'node..	7·70	226
,, .	Logie Coldstone Sch ..	3·94	128	*Mayo.*	Blacksod Point	7·64	147
,, .	Aberdeen Observatory.	3·22	109	,, .	Mallaranny.....	13·32	..
,, .	New Deer SchoolHouse	4·55	135	,, .	Westport House.....	9·01	184
Moray	Gordon Castle	3·12	108	,, .	Delphi Lodge.....	17·95	173
,, .	Grantown-on-Spey ...	2·75	92	*Sligo .*	Markree Castle.....	8·03	193
Nairn.	Nairn.....	2·19	93	*Cavan.*	Crossdoney, Kevit Cas.	7·18	..
Inv's .	Ben Alder Lodge.....	..	..	*Ferm .*	Crom Castle	7·58	218
,, .	Kingussie, The Birches	4·52	..	*Arm'h*	Armagh Obsy.....	4·90	173
,, .	Loch Ness, Foyers....	4·65	119	*Down.*	Fofanny Reservoir ...	7·78	..
,, .	Inverness, Culduthel R	2·84	111	,, .	Seaforde	5·02	132
,, .	Loch Quoich, Loan...	16·75	..	,, .	Donaghadee, C. G. Stn.	5·27	173
,, .	Glenquoich.....	15·47	138	*Antrim*	Belfast,Queen's Univ .	..	..
,, .	Arisaig House	9·41	140	,, .	Aldergrove Aerodrome	4·69	145
,, .	Glenleven, Corrour ...	11·88	159	,, .	Ballymena, Harryville.	5·20	128
,, .	Ft. William, Glasdrum	11·29	..	*Lon .*	Garvagh, Moneydig...	4·88	..
,, .	Skye, Dunvegan	9·72	..	,, .	Londonderry, Creggan.	5·94	145
,, .	Barra, Skallary	5·65	..	*Tyrone*	Omagh, Edenfel.....	7·12	187
R&C.	Tain, Ardlarach.....	3·50	108	*Don .*	Malin Head.....	5·22	128
,, .	Ullapool	5·29	99	,, .	Dunfanaghy	..	..
,, .	Achnashellach	11·47	126	,,	Dunkineely.....	7·97	..

Climatological Table for the British Empire, May, 1939

STATIONS.	PRESSURE.		TEMPERATURE.							Relative Humidity.	Mean Cloud Am'nt	PRECIPITATION.			BRIGHT SUNSHINE.	
			Absolute.		Mean Values.				Mean.							
	Mean of Day M.S.L.	Diff. from Normal.	Max.	Min.	Max.	Min.	½ Max. and Min	Diff. from Normal.	Wet Bulb.			Am'nt.	Diff. from Normal.	Days.	Hours per day.	Percentage of possible.
	mb.	mb.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	%	0–10	in.	in.			
London, Kew Obsy...	1018·1	+ 2·2	74	37	61·0	45·0	53·0	− 1·5	47·1	83	6·1	1·39	− 0·33	7	6·3	40
Gibraltar.....	1015·0	− 1·1	77	49	66·3	56·5	61·4	− 4·1	53·6	69	3·3	0·46	—	3	11·1	79
Malta.....	1012·0	− 2·5	74	54	68·3	58·8	63·5	− 2·4	58·2	74	5·5	0·42	+ 0·01	6	9·3	66
St. Helena	1017·0	− 1·2	69	58	66·5	59·1	62·8	+ 0·5	59·9	89	8·5	1·68	− 1·00	14	—	—
Freetown, Sierra Leone	1011·8	+ 2·3	90	70	87 2	74·3	80·7	--	73·2	87	8·5	8·94	− 2·53	11	—	—
Lagos, Nigeria	1010·4	− 0·2	91	69	86·8	74·3	80·5	− 1·3	75·3	93	8·0	12·43	+ 1·68	15	6·3	51
Kaduna, Nigeria	1009·8	—	94	64	86·4	69·0	77·7	− 2·2	70·9	88	6·7	7·61	+ 1·84	17	6·7	53
Zomba, Nyasaland....	1014·8	− 0·6	82	52	75·5	57·8	66·7	+ 0·9	62·9	80	4·2	0·14	− 0·90	2	—	—
Salisbury, Rhodesia ..	1018·0	− 0·3	80	42	73·2	49·0	61·1	+ 0·5	54·7	65	3·7	0·59	--	5	8·4	74
Cape Town	1018·1	0·0	85	45	71·1	52·7	61·9	+ 3·0	54·4	84	4·0	3·98	+ 0·23	9	--	—
Johannesburg	1019·0	+ 0·4	75	37	65·5	46·1	55·8	+ 1·4	46·8	58	1·7	1·75	+ 0·99	7	8·2	75
Mauritius	1017·3	+ 1·0	83	62	79·9	67·3	73·6	+ 1·0	69·6	72	4·7	1.73	− 2·19	18	8·8	79
Calcutta, Alipore Obsy.	1002·1	− 1·4	104	71	97·3	80·0	88·7	+ 2·6	80·9	79	6·5	2·74	− 2·82	6*	—	—
Bombay	1007·3	− 0·1	96	76	90·5	79·1	84·8	− 1·0	76·2	70	3·0	0·00	− 0·55	0*	—	—
Madras	1003·7	− 1·7	107	77	100·2	81·8	91·0	+ 1·2	77·4	63	5·3	0·00	− 1·84	0*	—	—
Colombo, Ceylon	1008·8	+ 0·4	88	71	86·2	78·6	82·4	− 0·4	78·6	81	7·8	13·03	+ 2·09	22	7·0	56
Singapore	1008·7	0·0	89	74	86·8	76·8	81·8	− 0·2	78·1	77	7·7	2·33	− 4·31	11	6·5	54
Hongkong.....	1008·0	− 1·1	89	67	80·8	72·5	76·7	− 0·7	72·7	83	8·2	20·99	+ 8·92	17	4·2	32
Sandakan	1008·4	--	91	75	87·7	77·8	82·7	+ 0·2	77·5	82	8·2	3·65	− 2·68	13	—	—
Sydney, N.S.W.....	1021·3	+ 2·7	78	47	69·4	54·1	61·7	+ 2·9	55·7	83	4·4	3·16	− 2·02	11	6·4	62
Melbourne	1021·6	+ 2·4	74	38	64·3	49·1	56·7	+ 2·6	51·9	80	7·3	1·98	− 0·18	16	3·5	34
Adelaide	1021·0	+ 0·8	83	44	69·5	52·4	60·9	+ 2·9	55·0	67	6·3	1·91	− 0·81	11	4·9	48
Perth, W.Australia....	1017·3	− 1·1	81	42	69·4	52·2	60·8	+ 0·1	55·8	73	5·5	7·80	+ 2·83	17	5·9	57
Coolgardie	1018·5	− 0·6	86	37	69·5	49·0	59·3	+ 1·6	52·6	70	3·6	0·32	− 1·01	4	—	—
Brisbane.....	1020·2	+ 1·6	81	51	73·7	58·1	65·9	+ 1·3	61·1	78	4·4	1·35	− 1·46	13	6·5	60
Hobart, Tasmania....	1019·8	+ 4·5	73	37	61·9	48·5	55·2	+ 4·7	49·4	75	6·3	1·50	− 0·40	10	4·8	49
Wellington, N.Z.....	1021·4	+ 5·8	64	40	56·7	47·0	51·9	− 0·9	49·6	79	6·5	2·28	− 2·40	13	3·4	34
Suva, Fiji	1012·8	+ 0·1	85	68	80·4	71·6	76·0	− 0·5	72·5	87	8·3	22·88	+12·81	28	2·2	19
Apia, Samoa	1010·6	− 0·5	88	70	85·3	73·7	79·5	+ 1·1	75·8	77	5·2	2·35	− 3·72	13	8·9	77
Kingston, Jamaica ...	1013·4	+ 0·3	89	68	86·4	71·4	78·9	− 0·8	71·2	77	4·2	1·38	− 3·01	7	7·4	57
Grenada, W.I.	1010·5	− 2·1	89	71	84·0	75·0	79·5	− 0·2	73·0	74	6	11·72	+ 7·53	23	—	—
Toronto.....	1014·6	− 0·3	86	35	67·4	48·3	57·9	+ 4·1	48·8	75	5·5	1·49	− 1·30	8	8·5	58
Winnipeg	1011·9	− 1·9	94	22	67·6	43·5	55·5	+ 3·5	44·2	75	6·6	1·37	− 0·63	13	7·5	49
St. John, N.B.	1014·2	+ 0·3	69	31	56·2	39·1	47·7	0·0	42·8	75	5·7	3·35	− 0·36	12	8·2	55
Victoria, B.C.....	1017·6	+ 0·9	78	42	61·9	46·7	54·3	+ 1·3	50·1	71	5·5	1·04	− 0·09	8	9·0	59

* For Indian stations a rain day is a day on which 0·1 in. or more rain has fallen.

(50094) Wt. 22/31 1375 12'39 Hw G.377/6